Introduction to the topic of the hands-on session

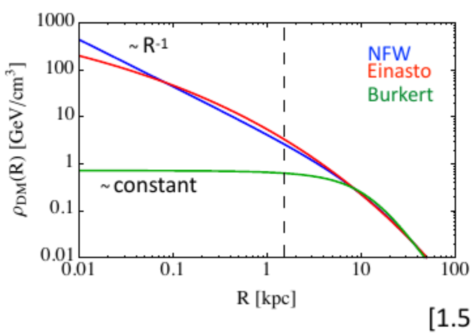
From F. Calore's lecture, you know that WIMPs can annihilate/decay into Standard Model particles, including photons.

The WIMP gamma-ray flux

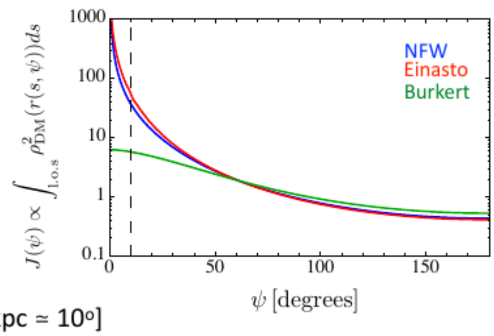
E.g: gamma-ray differential flux from spatial distribution ρ_{DM}

$$\frac{d\Phi_\gamma}{dE_\gamma}(E_\gamma, s, \Delta\Omega) \propto \frac{\langle\sigma v\rangle}{2m_{\mathrm{DM}}^2} \sum_i B_i \frac{dN_\gamma^i}{dE_\gamma} \frac{1}{4\pi} \int_0^{\Delta\Omega} d\Omega \int_{\mathrm{l.o.s}} \rho_{\mathrm{DM}}^2(s) ds$$

Dark matter density profiles:



Spatial distribution of the signal:

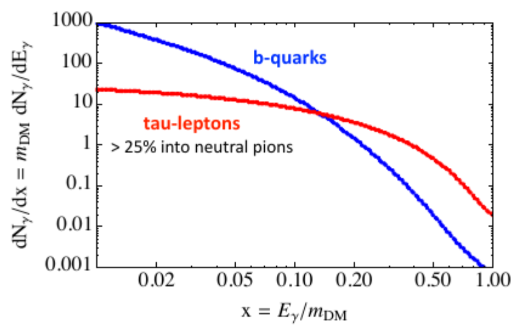


[1.5 kpc ≃ 10°]

Spectra of prompt "secondary" photons

$$\frac{d\Phi_\gamma}{dE_\gamma}(E_\gamma, s, \Delta\Omega) = \frac{\langle\sigma v\rangle}{2m_{\mathrm{DM}}^2} \sum_i B_i \frac{dN_\gamma^i}{dE_\gamma} \frac{1}{4\pi} \int_0^{\Delta\Omega} d\Omega \int_{\mathrm{l.o.s}} \rho_{\mathrm{DM}}^2(s) ds$$

100% Branching ratio (independent on PP model)

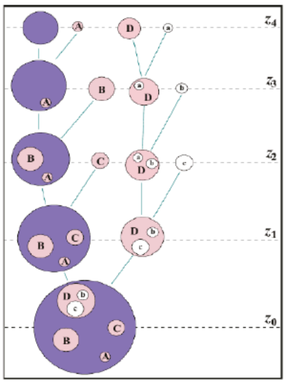


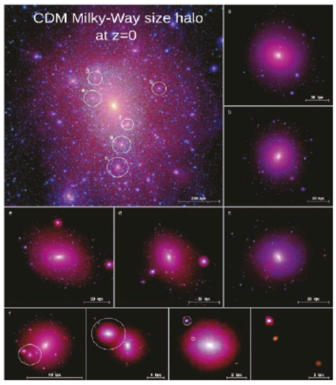
$$x \equiv \frac{E_X}{m_\chi}$$

$$\frac{dN_X}{dx} \equiv m_\chi \frac{dN_X}{dE}$$

Dark matter subhalos

Cosmological simulations: dark matter structures form *hierarchically*: halos contain large number of smaller substructures down to 10^{4-6} $M_\odot$





[Zavala,Frenk,Galaxies'19, Aquarius project]

Galactic/Milky Way-sized halo: more massive subhalos form dwarfs galaxies; a larger population of dark subhalos lacking bayonic matter with $dN/dM \sim M^{-1.9}$ is predicted

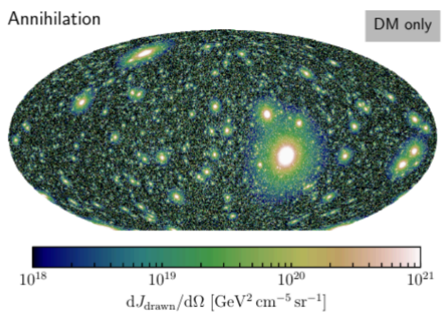
Wide research area both with numerical simulations and semianalytical models

[review: Sanchez-Conde&Doro,Galaxies'19]

Dark matter subhalos: signatures

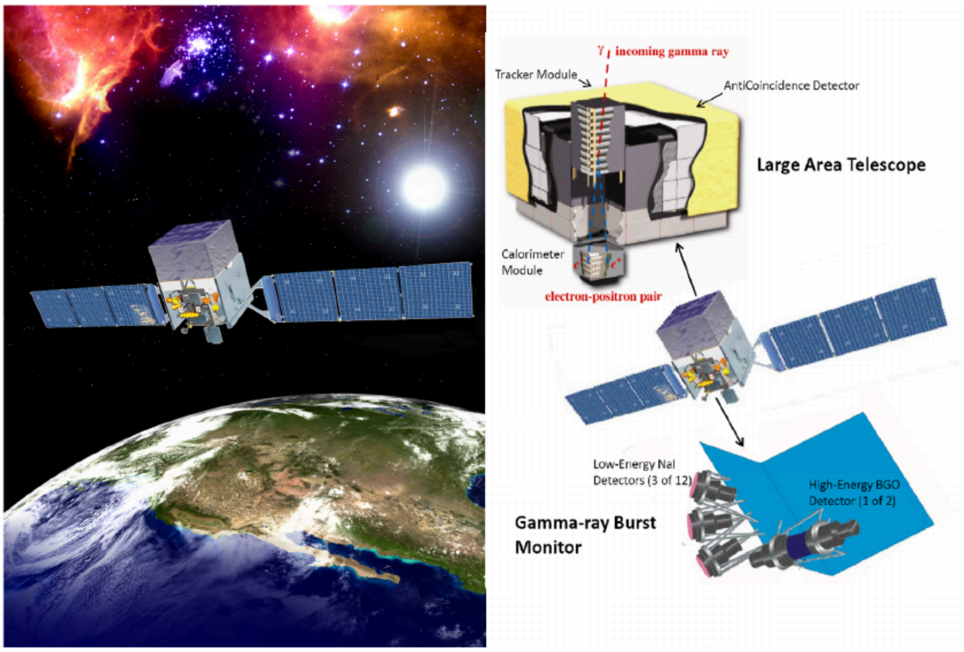
If particle dark matter at GeV-TeV scale (e.g. WIMPs) annihilates/decays in dark subhalos: they could shine as gamma-ray emitters in the sky:

$$\mathcal{J}_{\rm sub} \propto \int \text{dark matter density}^2$$



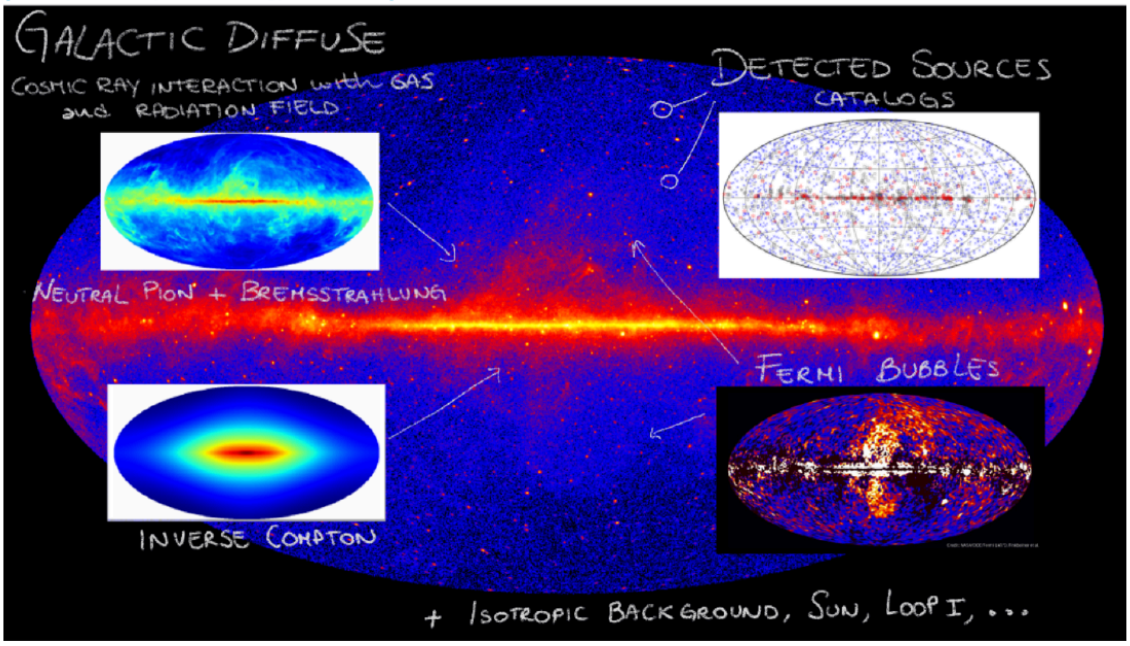
[Hutten+Galaxies'19]

The gamma-ray sky seen by Fermi-Large Area Telescope



Gamma-ray telescope, full sky survey, from 20 MeV to more than 300 GeV
12+years of publicy available data (NASA/DOE)

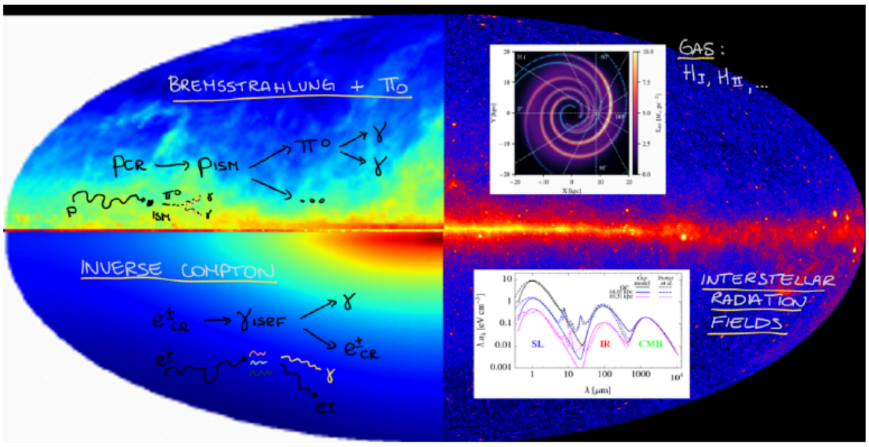
[Fermi-LAT 5 years, energy > 1 GeV]



wrt: Galactic diffuse emission

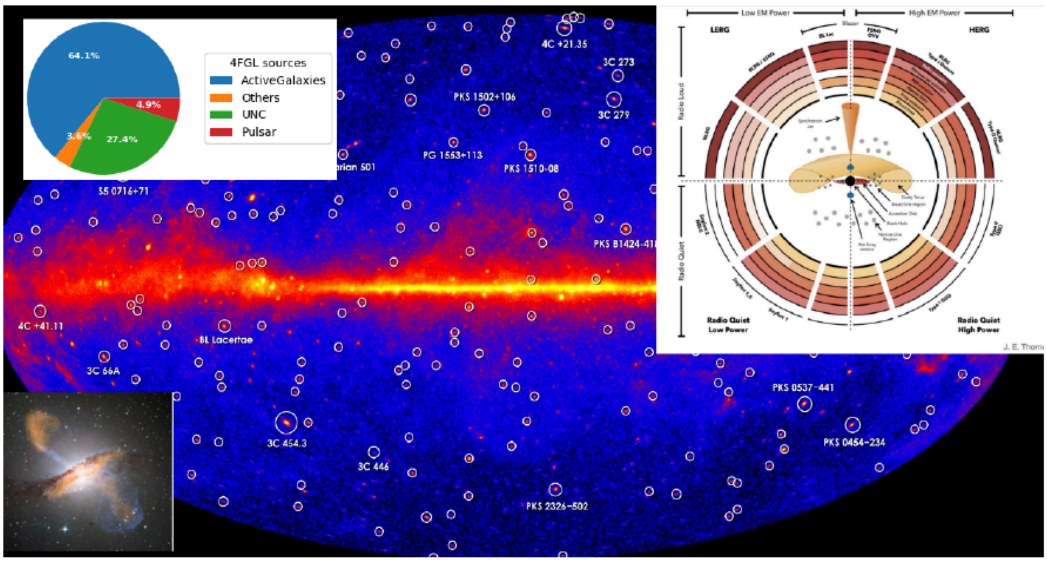
Produced by **charged cosmic rays**:

- Inject primary cosmic rays at source (mainly protons, few $e^{\pm}$)
- Propagate them in the Galaxy (code exists, Galprop, Dragon)
- **Interaction with gas and radiation fields**

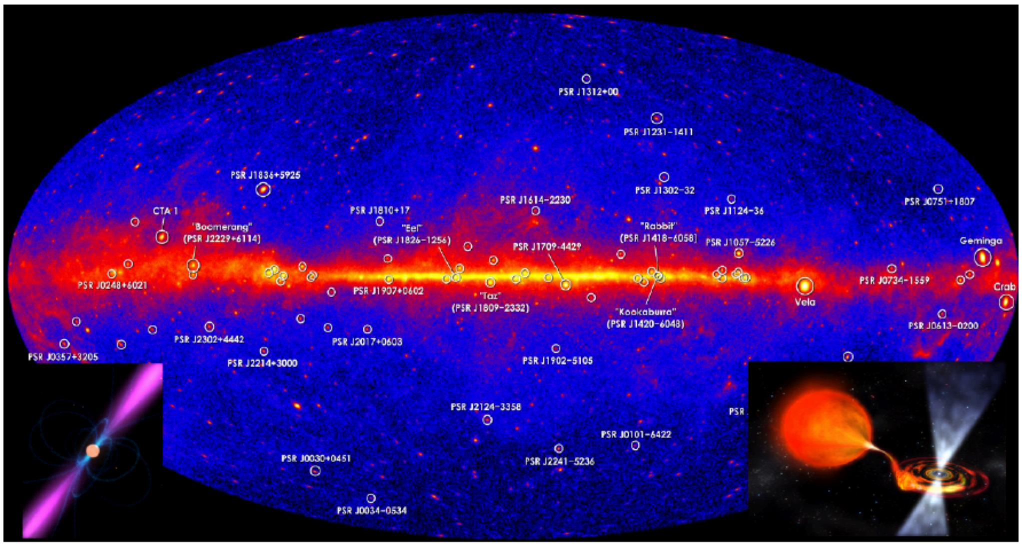


Final model: spatial + spectral template

Extragalactic: active galaxies, blazars



Galactic: pulsars and millisecond pulsars



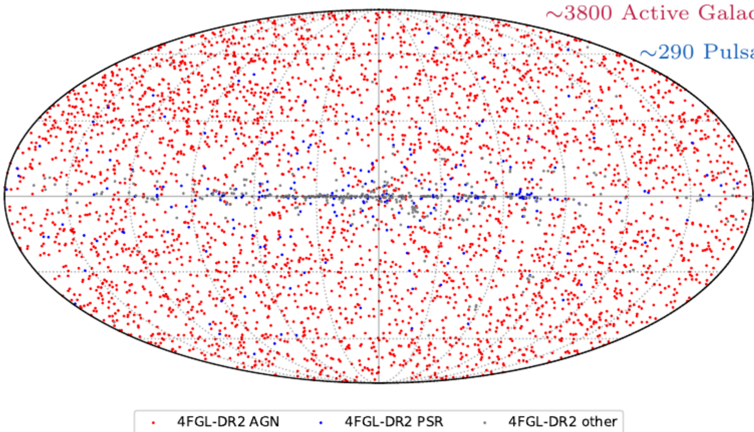
Catalogs of gamma-ray sources

Observatories such *Fermi*-LAT build incremental catalogs of individual sources, collecting their main characteristics:
position, flux(E, t) + computed/fitted features
Last: 4FGL-DR3 [Abdollahi et al, ApJS 260, 2022]

~6700 detected sources

~3800 Active Galactic Nuclei

~290 Pulsars



Majority of gamma-ray emitters are Active Galactic Nuclei and Pulsars

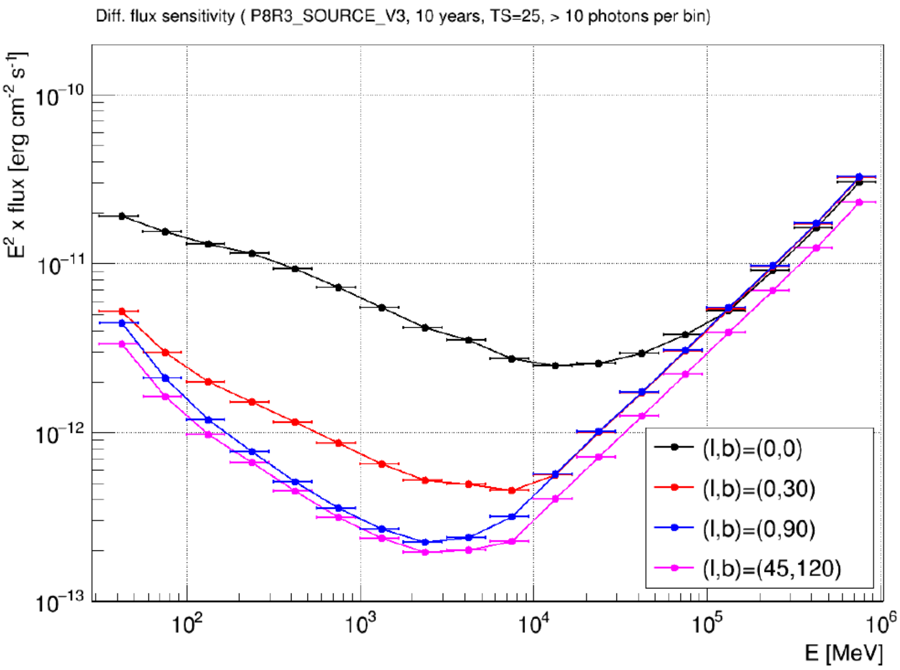


Figure 1: The Fermi-LAT point source sensitivity after 10 years of observations.
Adapted from https://www.slac.stanford.edu/exp/glast/groups/canda/lat_Performance.htm

Turning on the machines, connect to internet, setup the folders

- ☐ You should have a terminal open in the path: /home/graspa/Astroparticle_exercise and a Firefox page open in the school page
- ☐ Go to the timetable with presentations in the school page, and click on 'Numerical Tutorial'
- ☐ (slides)
- ☐ Type in the terminal 'conda activate fermipy'
- ☐ Type in the terminal 'jupyter notebook' ; a browser should open.
- ☐ Click on the name of the notebook

A PDF of the output of the notebook will be posted online.
If you want to have the source code to execute with your laptop, write to: manconi@lapth.cnrs.fr

That's all set, have fun!

(old)

- [ ] Turn on as written in the blackboard
- [ ] Connect to the internet: go to Activities and open a Firefox browser. Put the access code you should have collected
- [ ] Open a terminal
- [ ] Open to the Graspa page and download the .tgz file in the today's session
- [ ] Open a terminal, type: cd /home/graspa/Bureau
- [ ] Type: mkdir astroparticleTH/
- [ ] Move and untar the .tgz in this folder with 'tar -xvf namefile.tgz'
- [ ] File list should include: a .py, a notebook file .ipynb, and another .tgz file